STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION
ENGINEERING SERVICE CENTER
OFFICE OF MATERIALS ENGINEERING AND TESTING SERVICES

CONSTRUCTION EVALUATED RESEARCH REPORT:

CATHODIC PROTECTION SYSTEMS INSTALLED ON SUBSTRUCTURE SURFACES

CA-92-02
03-NEV-80 PM 59.44
03-377601
Yuba Pass Overhead and Separation
Bridge No. 17-23L/R

FINAL REPORT
DECEMBER 1995

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1.0 INTRODUCTION

Reinforced concrete structures may experience accelerated corrosion of reinforcing steel in areas where deicing salts are used. Affected components of a structure may include the bridge deck, the railings, the approach slabs, the girders, and portions of the bridge substructure. Substructure concrete may be exposed to deicing salts by contact with salt laden snow, deck drain runoff, and leakage of salt laden water through the deck joints.

Cathodic protection (CP) has been used as a corrosion mitigation method applied to bridge structures (primarily applied to bridge decks) (1). Caltrans has installed several bridge deck CP systems on bridges located in California's northern mountain regions. In addition, a CP system has been installed on a bridge substructure in the San Francisco Bay Area (2). However, Caltrans has not tested a CP system on a bridge substructure located in a non-marine, mountain region.

Current methods of monitoring the effectiveness of cathodic protection systems require frequent travel (weekly system measurements), the use of periodic lane closures, elaborate maintenance equipment (snoopers and manlifts) and exposure of workers to highway safety hazards. The use of a remote monitored cathodic protection system would decrease exposure of workers to traffic hazards by allowing system performance parameters to be monitored via an office computer.

2.0 OBJECTIVE

This report documents the installation of two CP systems (Caltrans Metallized Zinc CP system and Eltech's Elgard 210 CP system) on a portion of a reinforced concrete substructure located in a non-marine, mountain region. A remote monitoring system for collecting and monitoring CP system data and the distribution of corrosion protection was included in the CP installation. Additional information is presented on a conventional concrete patch and seal repair strategy performed on the remaining portions of the bridge substructure.

The long-range objective is to compare the effectiveness of the two CP systems in providing corrosion protection and to compare the performance of these systems with the conventional concrete patch and seal repair strategy.

3.0 BACKGROUND

3.1 Site Description

The bridge site is located in Northern California on Interstate Route 80 in Nevada County at the Yuba Pass Separation and Overhead, post mile 59.44. A site location map is shown in Figure 1. The site elevation is approximately 1600 meters (5250 feet). Seasonal rainfall and snowfall occur during the fall and winter months. The average annual precipitation measured at a nearby observation site is 1815 mm/year (71.5 inches/year).

The Yuba Pass Overhead and Separation is comprised of a separate left and right bridge (Bridge numbers 17-23 L and 17-23 R) originally constructed in 1963 (Figure 2 shows a plan view of the bridges). The left (westbound) bridge is a four span 157 meter structure. The right (eastbound) bridge is a four span 137 meter structure. Both bridges consist of reinforced concrete decks on steel I-beams that are supported by two reinforced columns at each of four bents (Figure 3).

Both the left and right bridges are subject to deicing salt application during the winter months. Drainage of salt contaminated deck runoff through deck drains adjacent to each bent, leakage of salt contaminated water through the deck joints, and direct contact of the columns to salt contaminated snow (from snow removal equipment) contributes to the high chloride exposure of the bridge columns and I-beam bearing pedestals of both bridges.

As-built drawings for the original construction of the bridges indicate that the deck drains were initially located within 0.5 meter of each bent on the left side (column 1 side) of each bridge. The drains had extensions that placed the pipe orifices below the bent cap. The close proximity of the drains to column 1 of each bent probably contributed to higher accumulated levels of chlorides, higher corrosion rates, and a greater amount of concrete spalling in the number 1 columns. In 1987, the drains were relocated several meters away from the bents to minimize exposure of the substructure concrete to salt contaminated deck runoff. However, during periods of high wind, deck runoff may still be blown onto the columns.

3.2 Previous Concrete Repairs

Transverse cracking and spalling of the reinforced concrete decks of both bridges were noted as early as 1967. A supplementary bridge report indicated that the deck surfaces were restored (patched, sealed, and an AC overlay was placed) in 1970.

Cracking, fracturing and some spalling of the column concrete due to corrosion of the reinforcing steel was noted as early as 1970 on the left column (column 1) of each bent. In 1971, portions of the bent caps were treated with chlorinated rubber in an attempt to seal the concrete surfaces. In late 1975, cracked and spalled portions of the bent caps and columns were repaired by removing unsound concrete, patching, and sealing with chlorinated rubber. Unfortunately, corrosion of the column reinforcing steel continued. Additional repairs to the columns at Bents 2, 3, and 4 of the left and right bridges were recommended in 1983.

The I-beam bearing pedestals were replaced between June, 1987 and May, 1988 due to excessive cracking of the concrete from reinforcing steel corrosion. In addition, the AC overlay and 50 mm (2 inches) of the existing reinforced concrete deck of each bridge were removed and replaced with a reinforced concrete overlay, 150 mm (6 inches) in depth. Reinforced concrete bolsters were added to Bents 2L, 2R, 3R, and 4R as a seismic design upgrade when the concrete bearing pedestals were replaced. The reconstructed bearing pedestals and added bolsters were constructed with epoxy coated reinforcing steel.

Corrosion of the column and bent cap reinforcing steel continued and in 1992 additional repairs were recommended. Repair strategies recommended included conventional repair (removal and patching of unsound concrete) with the application of a silane sealer, and removal and patching of unsound concrete with application of CP.

3.3 Preliminary Delamination Survey

A delamination survey performed in 1991 for each of the three bents of the left and right bridges provided a basis for estimating concrete removal quantities for the 1992 repairs. The quantities were based on visual observations and sample corings of the columns. Table 1 (shown on page 3) lists the estimated % delamination for each of the two columns at each bent.

BENT NUMBER	COLUMN	% DELAMINATION
2L	1	50
2L	2	0
3L	1	18
3L	2	0
4L	1	28
4L	2	0
BENT NUMBER	COLUMN	% DELAMINATION
2R	1	70
2R	2	30
3R	1	90
3R	2	0
4R	1	73
4R	2	48

TABLE 1: 1991 substructure concrete delamination estimate (Bridge Numbers 17-23L/R).

4.0 1992 SUBSTRUCTURE REHABILITATION & CP APPLICATION

4.1 Scope of work

The initial scope of the project consisted of removing unsound concrete, patching, installing two CP systems (Eltech's Elgard Mesh system on Bent 4L, and Caltrans Metallized Zinc system on Bent 4R), and applying a silane penetrant sealant to the substructure concrete of the remaining Bents.

Work items added to the original contract included replacement of severely corroded reinforcing steel, modifications to the CP systems (minor changes in zinc metallized area and adding shotcrete cover to portions of the Elgard CP system), and installing a cellular telephone unit for the remote monitoring system.

Work on the project started in August 1993 and was completed in February 1994.

4.2 Construction Review

4.21 Removal of Unsound Concrete

Work completed under this item included performing a delamination survey to determine the limits of unsound concrete and removing unsound concrete with pneumatic chipping tools. Table 2 (shown on page 4) lists the area of concrete removed for the left and right bridges.

Pay quantities for removing unsound concrete were calculated based on the number of cubic meters of concrete removed. Unsound concrete volumes were calculated for individual concrete removal areas and then added together for the total volume. The depth of unsound concrete was determined for each individual areas by taking the average of three depth measurements (after chipping away the unsound concrete). The final pay quantity for the removal of unsound concrete was 20 cubic meters (667 cubic feet) which represented 77 % of the original 25 cubic meters (870 cubic feet) estimated for removal.

BRIDGE NO.	BENT	LOCATION	COLUMN HEIGHT (METERS)	UNSOUND CONCRETE (SQ. METERS)	CONCRETE SURFACE AREA (SQ. METERS)	% DELAMINATION
17-23L	2L	BENT CAP	--------	13.6	123.9	11
		COLUMN 1	6.4	28.2	35.1	80
		COLUMN 2	3.0	0.9	16.7	5
		TOTAL	--------	42.6	175.8	24
	3L	BENT CAP	--------	5.4	88.0	6
		COLUMN 1	9.4	14.5	46.1	31
		COLUMN 2	7.0	1.2	34.2	3
		TOTAL	--------	21.1	168.2	13
	4L	BENT CAP	--------	6.5	88.0	7
		COLUMN 1	7.6	11.3	37.2	31
		COLUMN 2	10.1	2.4	49.1	5
		TOTAL	--------	20.3	174.2	12
17-23R	2R	BENT CAP	--------	11.1	119.2	9
		COLUMN 1	7.0	21.6	38.5	56
		COLUMN 2	5.2	8.0	28.4	28
		TOTAL	--------	40.8	186.1	22
	3R	BENT CAP	--------	17.9	119.2	15
		COLUMN 1	9.1	39.9	50.2	80
		COLUMN 2	7.9	1.9	43.5	4
		TOTAL	--------	59.7	212.8	28
	4R	BENT CAP	--------	4.7	119.2	4
		COLUMN 1	7.3	24.2	40.1	60
		COLUMN 2	8.8	24.0	48.5	49
		TOTAL	--------	53	207.8	25

TABLE 2 - Area of unsound concrete removed.

Prior to chipping the unsound concrete at a bent, an enclosure was constructed to contain the construction debris (concrete fragments, abrasive blast material, dust, and shotcrete overspray). This minimized contamination of the soil and nearby seasonal creek and prevented the construction debris from entering the roadway of Route 20 at Bents 4L and 4R. The enclosure consisted of netting and flexible, fiber reinforced plastic sheeting suspended from the scaffolding surrounding each bent (Figure 4 and 5). The sheeting was placed on the outside of the scaffolding so that workers could move freely to each level.

Severely corroded confinement reinforcing steel (No. 4 rebar) was found at some locations (Figures 6, 7 and 8) after unsound concrete was removed. In some cases, there were losses of cross-section greater than 75% for the confinement steel due to corrosion. A contract change order was issued to replace confinement reinforcing steel at all locations where corrosion had removed more than 25% of the original reinforcing steel cross-sectional area.

The confinement reinforcing steel was replaced by either replacing an entire segment (hoop), or by cutting out the corroded section and lap-splicing replacement reinforcing steel of appropriate length to the remaining portion of reinforcing steel. Lap splices were welded with a minimum 300 mm (12 inch) splice overlap. All welding was performed by certified welders in accordance with Sections 4-103, 4-1103D, and 9-1.03 of the Caltrans Standard Specifications. The replacement reinforcing steel was tied onto the vertical column steel to maintain the original 300 mm (12 inch) confinement steel spacing.

Replacing the vertical No. 11 column reinforcing steel was not necessary since corrosion of these bars was limited to minor surface pitting in a few locations. The vertical No. 11 bars had in general 80 mm (3 inches) or greater of concrete cover.

4.22 Patching of Concrete

Chipped concrete areas were repaired with shotcrete. The shotcrete was applied using a dry mix shotcrete pump (Figures 9 and 10). Sand and cement were added to a mixing hopper and pumped dry through the delivery hose to the shotcrete nozzle where water was added through a pressure ring. The amount of water added to the mix was controlled by the nozzle operator. The shotcrete mix design was in accordance with Section 53 of the Caltrans Standard Specifications.

Three nozzle operators applied shotcrete at various times throughout the project. Each nozzle operator was pre-qualified to place shotcrete on the project. Pre-qualification included the production of three test panels by each operator. The test panels were cored and tested for compressive strength after 7 days of moist curing. All test panels exceeded the minimum 28 day strength of 22400 kPa (3250 psi) in only 7 days.

Prior to applying shotcrete, the entire concrete surface was roughened by sandblasting to remove some of the cement paste and expose the fine aggregate. This created a rough surface for the shotcrete to bond to. Approximately one hour before any shotcrete was applied, the existing concrete surface was sprayed with water to minimized water loss from the freshly applied shotcrete to the existing concrete. Waiting one hour between spraying the water and applying the shotcrete produced a surface saturated dry (SSD) condition in which the existing concrete was moistened, but free of excess surface water.

The shotcrete was moist cured by wrapping the freshly shotcreted surface with plastic and spraying water daily behind the plastic with a hand-held sprayer. This process was continued for 7 days after shotcrete was applied.

Salt (sodium chloride) was added to the repair shotcrete applied to Bents 4L and 4R (Elgard and Metallized Zinc systems). This technique helps to uniformly distribute the protective CP current by making the shotcrete approximately as conductive as the remaining original structure concrete. The amount of salt added to the shotcrete was 2.4 kg salt/m^3 shotcrete (4 lbs salt/cy shotcrete). This amount was based on the chloride results of concrete cores taken in 1991 that showed a chloride concentration of approximately 1.4 kg chloride/cubic yard concrete (2.4 lbs chloride/cubic yard concrete).

Some cracking of the shotcrete occurred within the first month immediately following the shotcrete application. Some cracking occurred in the shotcrete applied at each bent location. The cracks are, in general, less than 2 mm (1/16 inch) wide. A larger number of cracks are present at Bent 4R (zinc metallized surface). Cracks at Bent 4R form a random "map pattern" over the repaired shotcreted surfaces. There are less cracks at the other bents and they do not exhibit a "map pattern". The cracks may have been due to plastic shrinkage of the shotcrete. Fiber reinforcement was not used in the shotcrete mix.

4.23 CP System Installation

Zinc CP System

The Metallized Zinc CP system consists of a constant voltage DC rectifier to supply the protective CP current, a total of four brass anode pads (primary connections wired to the CP rectifier) epoxied flush to the surface of the concrete at separate locations on the bent cap above the northeast and southwest faces of each column, and metallized zinc (for distributing CP current to the bridge substructure). The zinc alloy wire used for the metallized zinc had a 99.9 % purity rating.

The metallized zinc was applied using an arc spray system. This equipment consisted of an arc spray gun, an air compressor, an electric power unit, and an electrical short detection device. The electrical short detection device was used to monitor the electrical resistance between the metallized zinc and the reinforcing steel (embedded in the concrete). The metallizing process was automatically interrupted if a direct electrical connection was made between the metallized zinc and the reinforcing steel. Figures 11 through 13 show the zinc metallizing equipment, the metallizing operation, and a view of the metallized concrete surface. Figures 14 and 15 show the brass anode pads before and after zinc metallizing was applied.

Prior to metallizing, the concrete surface was roughened by sandblasting to remove some of the cement paste and to expose the fine aggregate. This provided a rough surface for the zinc to bond to. After sandblasting, near surface metal (tie-wire) was detected with the use of a portable metal detector. Several tie wires located within 6 mm (1/4 inch) of the concrete surface were removed by drilling at the location and patching with an epoxy grout material. Two additional electrical shorts (contacts between exposed near surface metal on the concrete exposed and the sprayed zinc anode material) were detected during the metallizing process. Each time a short was detected, the spray gun was automatically shut off so that the electrical shorts could be located and removed.

Zinc metallizing was performed over a three day period within the same enclosure used to contain debris from the concrete removal and shotcreting operations. Workers operating within the enclosure for extended periods of time during the metallizing operations wore filtered air supply helmets. Other workers who were momentarily exposed to zinc dust wore portable filtration masks. Propane heaters were used within the enclosure to maintain the surrounding air and concrete above 21 degrees C (70 degrees F) prior to metallizing.

Periodic thickness measurements of the zinc coating were made to ensure compliance with contract specifications of 330 to 430 micrometers (13 to 17 mils).

Zinc thickness measurements were made with a micrometer. Small pieces of duct tape, 50 x 50 mm (2 x 2 inches), were randomly placed on the concrete prior to metallizing. After metallizing a small area, the tape within the area was removed and the zinc was pealed off and checked for thickness. If the thickness was not according to specifications, additional passes were made over the affected region to produce the desired zinc thickness.

Elgard CP System

The Elgard CP system consists of a constant voltage DC rectifier to supply the protective CP current, titanium alloy strips (primary connections wired to the CP rectifier), and a titanium alloy mesh (Elgard 210 mesh) to distribute the protective CP current to the concrete. The titanium alloy strips were placed along the northeast and southwest faces of the bent cap and columns and were resistance welded to the mesh anode. Figures 16 and 17 show details of the Elgard anode mesh and a primary anode strip.

Prior to placing the anode mesh, the entire concrete surface was roughened by sandblasting to remove some of the cement paste and to expose the fine aggregate. After sandblasting, near surface metal (tie wire) was detected with the use of a portable metal detector. An unusually large amount of tie wire was found within 6 mm (1/4 inch) of the concrete surface on the bent cap at Bent 41. This probably occurred when the ends of twisted wire ties were not trimmed off after reinforcing steel was tied during the original construction of the bent cap. Rather than trying to eliminate all of this near surface metal, a 15 mm (1/2 inch) layer of shotcrete was added to the original concrete surface prior to placing the mesh. This additional shotcrete was placed when spalled areas in the bent cap were repaired. Salt was added to this shotcrete at an amount of 2.4 kg salt/m^3 shotcrete (4 lbs salt/cy shotcrete).

The titanium mesh was attached to the concrete surface with plastic anchors placed into 25 mm deep holes drilled into the concrete at the manufacturers recommended spacing of approximately 600 mm (2 feet). The mesh was placed in sections. A portable voltmeter (connected to the reinforcing steel and titanium mesh) was used to monitor for electrical shorts. Each section of mesh was resistance welded to the titanium alloy strips. No electrical shorts were detected during placement of the mesh.

After the mesh was installed, a nominal 50 mm (2 inches) of shotcrete was added as cover over the mesh. Salt was not added to the shotcrete covering the titanium mesh since the path of least resistance for the CP current is toward the substructure surface.

4.24 CP Monitoring Equipment

Remote Monitoring System

The remote monitoring system is composed of a Campbell Scientific 21X Datalogger, a telephone modem, and a Telular 4-line cellular phone unit. These components are housed in a traffic control cabinet with the DC rectifiers. The traffic control cabinet provides a water tight enclosure to house the CP systems and remote monitoring system and permits easy access to all components during system checks. Figures 18 and 19 show the CP cabinet and CP system components.

The Campbell datalogger records the driving voltage and the CP current for the Metallized Zinc and Elgard CP systems, the electrical potential of the graphite reference cells, and the datalogger battery voltage. These parameters are measured and recorded every three hours and are stored in the datalogger's memory. Approximately six months of data may be stored in the datalogger with its current program configuration. Stored data can be downloaded into a PC with the use of the Campbell Scientific PC208 datalogger support software. The software operational program and recording procedures were developed in part (with the assistance of Weather Network, Inc.) by the Caltrans' Corrosion Technology Section. The Corrosion Technology Section routinely monitors the operation of the Elgard and Metallized Zinc CP systems and maintains a data file of the CP operational parameters.

The telephone modem and cellular phone unit was added as a contract change order and was paid for with unused contract funds available from the removal of unsound concrete estimated pay quantities. The phone permits stored data to be downloaded from the remote site to an office location. A cellular phone was used at the Yuba Pass site since a conventional phone line was not available.

Reference Cell Installation

A pair of graphite reference cells were installed at separate locations for the Metallized Zinc and Elgard CP systems. These reference cells can be used to measure the electrical potential of the embedded reinforcing steel. Graphite reference cell locations were chosen based on an electrical potential survey that indicated where the most corrosive areas were located. When the CP systems are supplying current to the structure, the shift of the reinforcing steel in these areas can be monitored with the graphite reference cells. The graphite reference cells were backfilled with a portland cement grout containing 2.4 kg/m^3 (4 lbs/cy) of salt. Figures 20 and 21 show a graphite reference cell being placed and grouted.

Long term performance of graphite reference cells embedded in concrete has not been established. Therefore, in addition to the graphite reference cells, external ports constructed of PVC were added at several locations for measuring the potential of the reinforcing steel (see Figure 22). These ports may be used with the more conventional copper/copper sulfate reference cell for monitoring electrical potential of reinforcing steel in concrete. The copper/copper sulfate reference cells are portable reference cells that are brought to the site for use during CP system checks. Their accuracy can be easily checked at a lab prior to their use in the field. Drawbacks in using these portable reference cells are that they must be placed and removed each time they are used (access to all desired locations is not always easily obtained), they must be held steady during measurement, and the surface to be measured must be moistened slightly to minimize contact resistance (a source of measurement error).

Corrosion Null Probes

In addition to the graphite reference cells, four corrosion null probes were installed at the most corrosive areas (two probes per CP system, installed as a contract change order). Corrosion null probes are an experimental Strategic Highway Research Program (SHRP) product used to evaluate the effectiveness of reinforced concrete CP systems. The null probes are segments of existing reinforcing steel (located in one of the most anodic locations) that are cut to isolate them from the rest of the reinforcing steel (Figure 23). CP current can be monitored through a resistor connected to the probe and adjoining reinforcing steel. By knowing the location and surface area of the probe, the current density (amount of CP current per steel surface area) for a particular location can be calculated. The two corrosion null probes at Bent 4R were constructed from separate segments of No. 4 confinement steel. One corrosion null probe at Bent 4L was constructed from a segment of No. 4 confinement steel, and the second probe was constructed from a segment of No. 5 rebar located in the bent cap.

4.25 Silane Penetrant Sealant

A silane penetrant sealant was applied to Bents 2 and 3 of the left and right bridges after removing the unsound concrete, replacing severely corroded confinement reinforcing steel, and placing the shotcrete. The silane penetrant sealant was applied to the dry shotcreted surfaces with rollers and brushes (Figure 24). A fugitive dye was used to indicate where the sealant was applied. The effectiveness of the silane sealant in preventing reoccurrence of reinforcing steel corrosion and subsequent spalling of repair surfaces will be compared with the effectiveness of the CP systems. The sealant should reduce the ingress of moisture and chlorides into the concrete, however, residual chloride and moisture within the concrete may lead to continued corrosion of the reinforcing steel. Cracks formed in the shotcreted surface after application of the sealant may also provide additional paths for moisture and chloride and lead to further corrosion.

No major problems were encountered in the application of the silane sealant. The coverage was estimated at 2 m^2/L (80 ft^2/gal) which was within the maximum manufacturer recommended coverage of 2.5 m^2/L (100 ft^2/gal). The only noticeable problem was with the fugitive dye. The dye (violet in color) remained visible well beyond the 24 hour time specified by the manufacturer. A noticeable amount of color still remains 24 months after the sealant was applied. The cause of the residual dye is not known since the amount of dye added to the sealant was in accordance to the manufacturers suggested practice (the manufacturer's pre-measured portions were used).

4.26 Contract Change Orders & Project Costs

The total project cost for the removal of unsound concrete, patching, installing the CP systems, sealing the bents that did not receive CP, and additions due to Contract Change Orders was \$320,000. The cost per unit area (excluding the cost of concrete repair and including the cost of the remote monitoring equipment) was \$355/m^2 (\$33/ft^2) for the Metallized Zinc CP system and \$376/m^2 (\$35/ft^2) for the Elgard CP system. These per unit costs were based on the awarded contractors bid and added change order costs. The per unit costs may vary depending on the size and complexity of individual projects.

Nine contract change orders (CCO's) were issued as follows:

- <u>CCO No. 1</u> provided a lump sum increase to the contractor of \$5000 for erecting and maintaining a traffic control system at the site and providing for vehicle flagging.

- <u>CCO No. 2</u> provided an additional \$4000 to the contractor through force account for modifications of the CP system at Bents 4L and 4R to include the addition of corrosion null probes (two at each bent). **<u>Reasoning:</u>** The corrosion null probes were added after initiation of the original contract. These probes are an experimental Strategic Highway Research Program (SHRP) product.

- <u>CCO No. 3</u> provided a lump sum increase to the contractor of \$600 for the addition of sodium chloride to the shotcrete mix for those regions of the substructure that were to receive CP. **<u>Reasoning:</u>** This item was inadvertently left out of the original contract specifications.

- <u>CCO No. 4</u> provided an additional \$15548 to the contractor through force account for the replacement of severely corroded reinforcing steel. **<u>Reasoning:</u>** The extent of corrosion damage to the reinforcing steel was not realized prior to initiating the contract.

- <u>CCO No. 5</u> provided a lump sum increase of \$257 to the contractor for modifications to the CP systems at Bent 4L and 4R. This included modifying the CP systems to exclude areas of the bent caps that have epoxy coated reinforcing steel and adding silane sealant to those portions of the bent caps that have epoxy coated reinforcing steel. **Reasoning:** Electrical continuity is required to transfer protective CP current to all reinforcing steel. Isolated reinforcing steel not connected to the CP rectifier will not be protected against corrosion and may even corrode at an accelerated rate. Review of As-built drawings for previous replacement of the bearing pedestals and addition of reinforced concrete bolsters showed that epoxy coated reinforcing steel was used. Since electrical continuity of the epoxy coated reinforcing steel with the uncoated reinforcing steel in the remaining structure could not be guaranteed, CP was eliminated from the pedestals, bolsters, and portions of the adjacent concrete for both the Zinc and Elgard CP systems. The zinc metallizing and Elgard mesh were kept 50 mm clear of the bolsters and bearing pedestals to minimize stray CP current from passing to the epoxy coated reinforcing steel.

- CCO No. 6 provided a lump sum increase of $1680 to the contractor for modifications of the CP system (routing of PVC conduit to an alternate power source location, and installing the rectifier and remote monitoring equipment into a traffic control signal box). **Reasoning:** The original plans showed the AC power source for the proposed CP systems at an existing sand and storage building located adjacent to the bridge structures. Since the main AC panel for the sand facility was actually located in an existing fuel and maintenance work building, minor changes in wiring and placement of PVC conduit were needed. In addition, a traffic control box was used to house the CP rectifiers and remote monitoring equipment rather than the NEMA enclosure specified in the contract specifications. The traffic control box permits easy access to the CP equipment, better protection against weather, and provides better security for the equipment. A light bulb (used as a heat lamp) was added to the traffic control box and is connected to a temperature controlled switch to help maintain the CP components at temperatures above freezing.

- CCO No. 7 provided a lump sum increase of $1000 to the contractor to mobilize equipment at Bent 4L for placing 1.5 cm of additional shotcrete prior to placement of the Elgard mesh. Applicable materials and labor costs were paid for with available contract funds for placement shotcrete at the contract price of $1589 per cubic meter. **Reasoning:** Additional shotcrete was needed at Bent 4L prior to placing the Elgard mesh to eliminate the possibility of contact between the mesh and the large amount of surface metal that was found.

- CCO No. 8 provided a lump sum increase of $2100 to the contractor for additional railroad flagging operations. **Reasoning:** Time delays occurred that were not necessarily the fault of the contractor. As a result, additional railroad flagging was needed and was paid for through this contract change order.

- CCO No. 9 provided an additional $ 9,675 to the contractor through force account to install a cellular telephone system. **Reasoning:** A telephone system was not included in the original contract plans and specifications. A phone system was needed to utilize the remote monitoring capabilities of the CP datalogging system. A cellular phone system was chosen for the site since a land-line did not exist within a reasonable distance.

4.27 Contact Acceptance and Additional Notes

Contract Acceptance

By February, 1994, all work was completed and the CP systems were operating satisfactorily. No contractor claims were filed against Caltrans for this project. Figures 25 and 26 show the completed project.

Additional Notes

On March 10, 1994 lightening damaged the Campbell datalogger and the Metallized Zinc CP rectifier. The CP rectifiers had DC lightening protection devices across the positive and negative rectifier output leads and an AC lightening protection device across the AC power input lines to the CP system. The electrical ground for the CP systems as originally connected was provided through a third wire ground lead connection (from the AC power input lines) to an existing ground rod for the nearby Caltrans fuel and maintenance work building located approximately 90 meters (300 feet) from the rectifier location.

Repairs were made to the damaged components and additional lightening protection devices were added after reviewing the latest available literature regarding lightening protection for electrical components and consulting with members of the Caltrans Electrical and Commodities Testing Section. Metal oxide varistors (MOV's) were added to all input and output lines of the Elgard and Metallized Zinc CP systems for additional lightening protection. These devices provide a shunt to ground if large transient spikes or surges occur in the CP system wiring and components during storm events. MOV's with different energy ratings were stacked in parallel on input and output lines of the CP systems to provide lightening protection against a wide range of transient responses. Figures 27 through 29 are schematic diagrams that show the added MOV's.

In addition to installing the MOV's, local ground rods were installed between the left and right bridges at Abutment 5. This location placed the ground rods at a closer proximity to the CP rectifiers than the original ground at the existing fuel and maintenance work building. The ground rods are copper clad steel rods approximately 2.4 meters (8 feet) in length. Two rods were coupled together to make a single segment of rod approximately 4.8 meters (16 feet) in length. Two of these segments were connected to the Elgard CP system ground and two were connected to the Metallized Zinc CP system ground.

The ground rods were placed horizontally in two separate trenches (one each for the Elgard and Metallized Zinc CP systems) approximately 0.9 meters (3 feet) deep. The large amount of bedrock at the site prevented installing the rods vertically either by driving or augering. A front-end loader was used to dig trenches. Wire leads from the rods to the CP system grounds were routed through PVC conduit and buried in trenches approximately 0.8 meters (2.5 feet) deep.

Three 27 kg (60 lb) bags of Bentonite material were distributed over the rods in each trench to improve the conductivity to of the rods to ground. In addition, salt from the on-site maintenance facility was added as a partial backfill material over the ground rods (also to increase the conductivity to ground). The remaining fill consisted of soil from the original excavation.

The CP systems were returned to operational service on November 10, 1994. Since installing the ground rods and lightening protection devices, the CP systems have not been damaged by lightening.

5.0 CONCLUSIONS

The substructure repairs and installation of the Elgard and Metallized Zinc CP systems were completed within a reasonable time, without any major problems, without changes to the plans or specifications, and with minimal disruption to the public and environment. This is attributed in large part to the experience of the contractor and subcontractors involved in the project.

The primary contractor for the project was familiar with performing repairs to bridge substructure concrete and had worked as a subcontractor for the Oregon Department of Transportation on several repair projects that included installing CP systems. The subcontractor that performed the zinc metallizing was experienced in metallizing concrete and had also worked with the Oregon Department of Transportation on several CP projects. Eltech Corporation (manufacturer of the Elgard 210 mesh used for the Elgard CP system) provided oversight during the installation of the Elgard mesh for the Elgard CP system.

Plans and specifications for the project were produced by Caltrans. The Corrosion Technology Section provided additional assistance during the construction phase of the project including technical oversight for installing the CP systems, and full time on-site construction inspection.

The Elgard and Metallized Zinc CP systems were energized at the completion of the project and appear to be operating satisfactorily. Some of the electrical components of the Metallized Zinc CP system were damaged during an electrical storm within the first several months of operation. Repairs were made to the damaged components, and additional lightening protection devices and ground rods were installed. Since installing the additional lightening devices and ground rods, the CP systems have not been damaged by lightening.

The Corrosion Technology Section will monitor the performance of the Elgard and Metallized Zinc CP systems to determine their effectiveness in providing corrosion protection at the Yuba Pass site and to compare the cost effectiveness of CP with the conventional concrete patch and seal strategy.

6.0 FIGURES

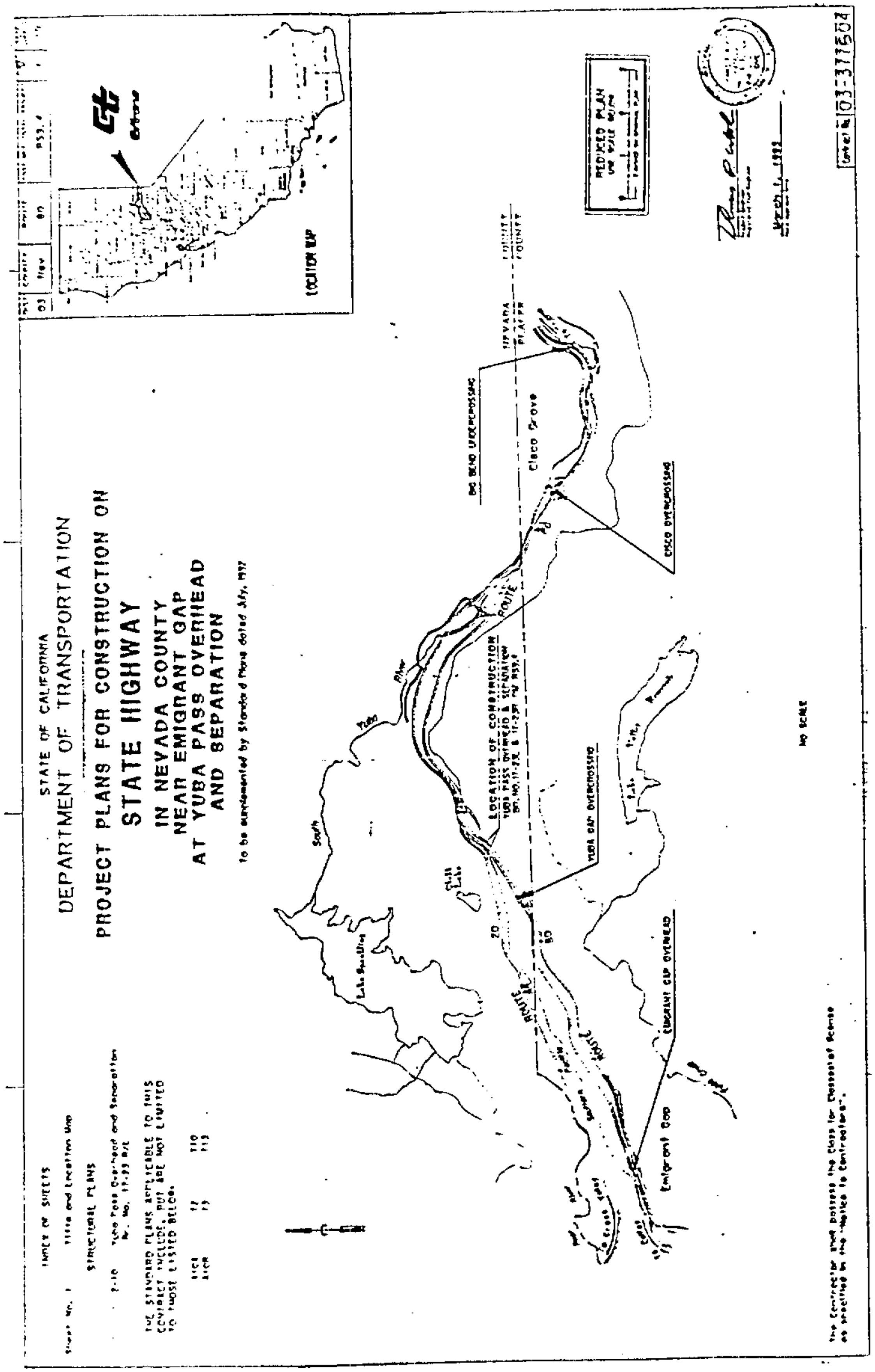

Figure 1. Yuba Pass Overhead and Separation (Bridges 17-23L/R) site location map

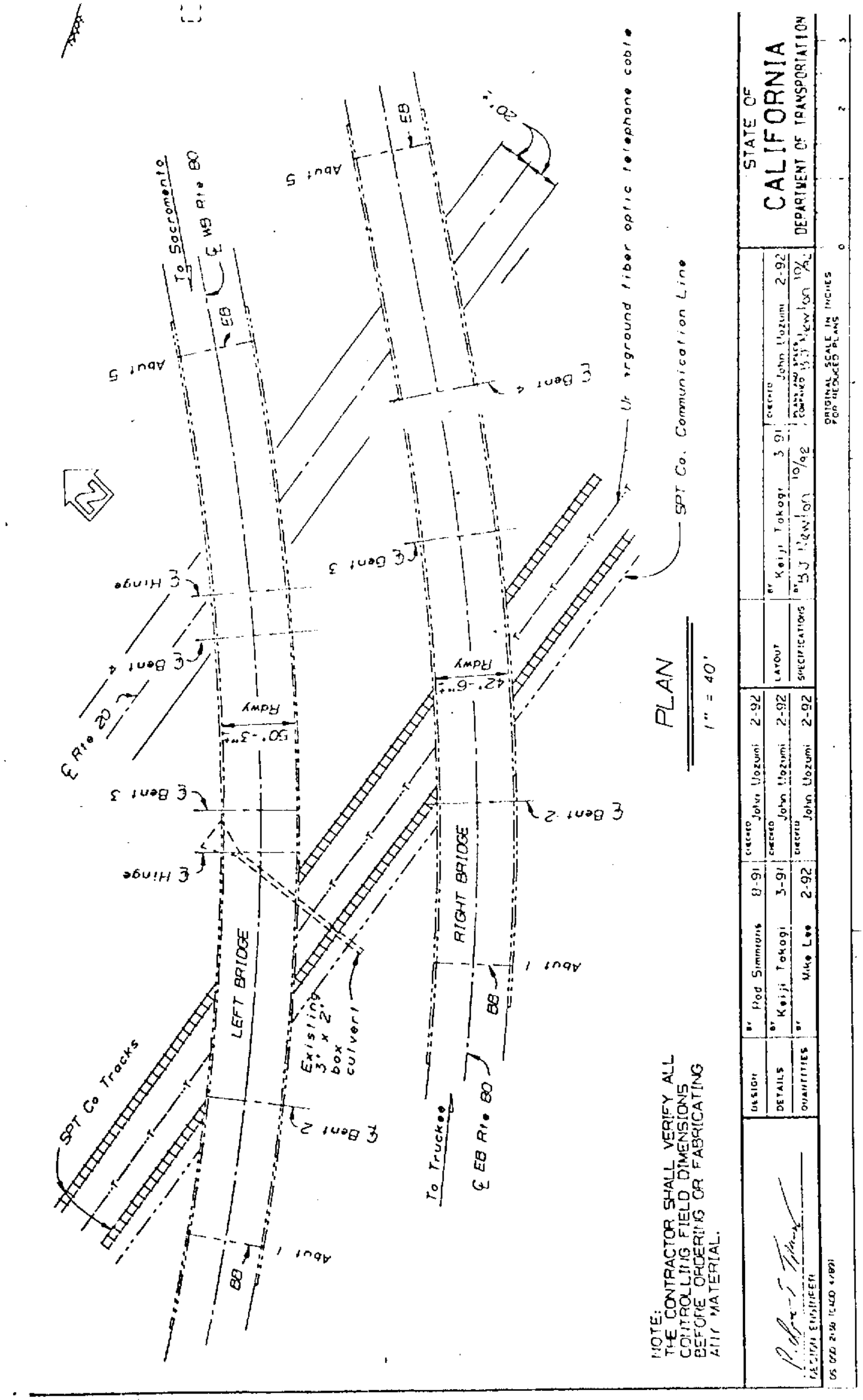

Figure 2. Plan view of Yuba Pass Overhead and Separation (Bridges 17-23 L/R).

Figure 19. Close up view inside the CP control cabinet showing the CP system components.

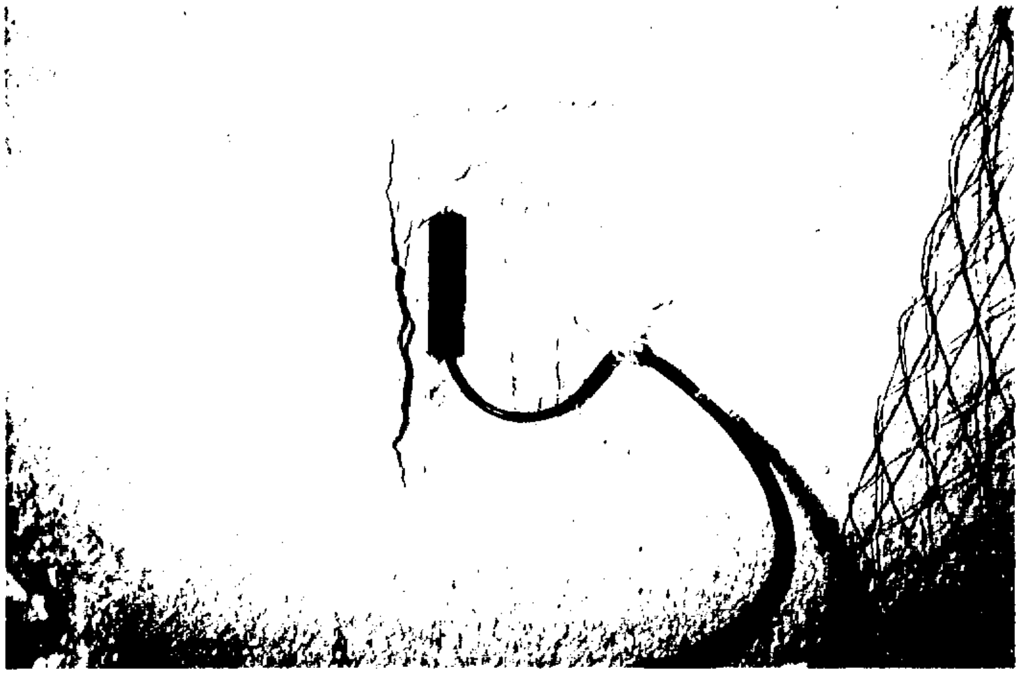

Figure 20. View of a graphite reference cell. The reference cells were grouted in-place next to the reinforcing steel. The reference cells will be used to monitor the electrical potential of the reinforcing steel. This will give an indication of the level of protection provided to the steel.

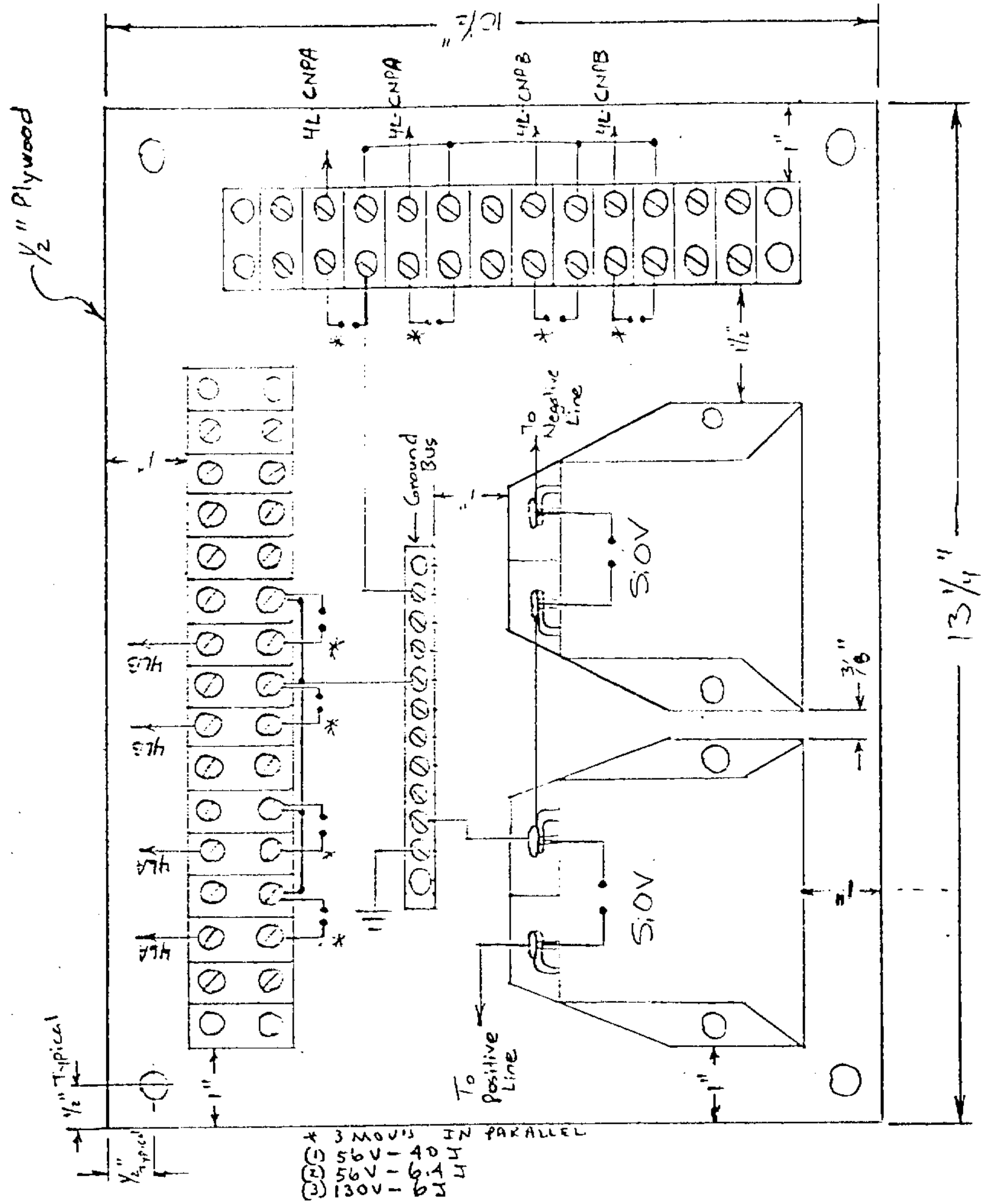

Figure 27. Schematic diagram of metal oxide varistor (MOV) board used for lightening protection of the power leads, reference cell leads, and corrosion null probe leads to Bent 4L (Elgard CP system). The MOV's provide a shunt to ground if large spikes or surges occur due to electrical storms. Three MOV's with different energy level ratings were used in parallel to protect against a wide range of electrical and/or surges. The board was mounted at the CP control cabinet.

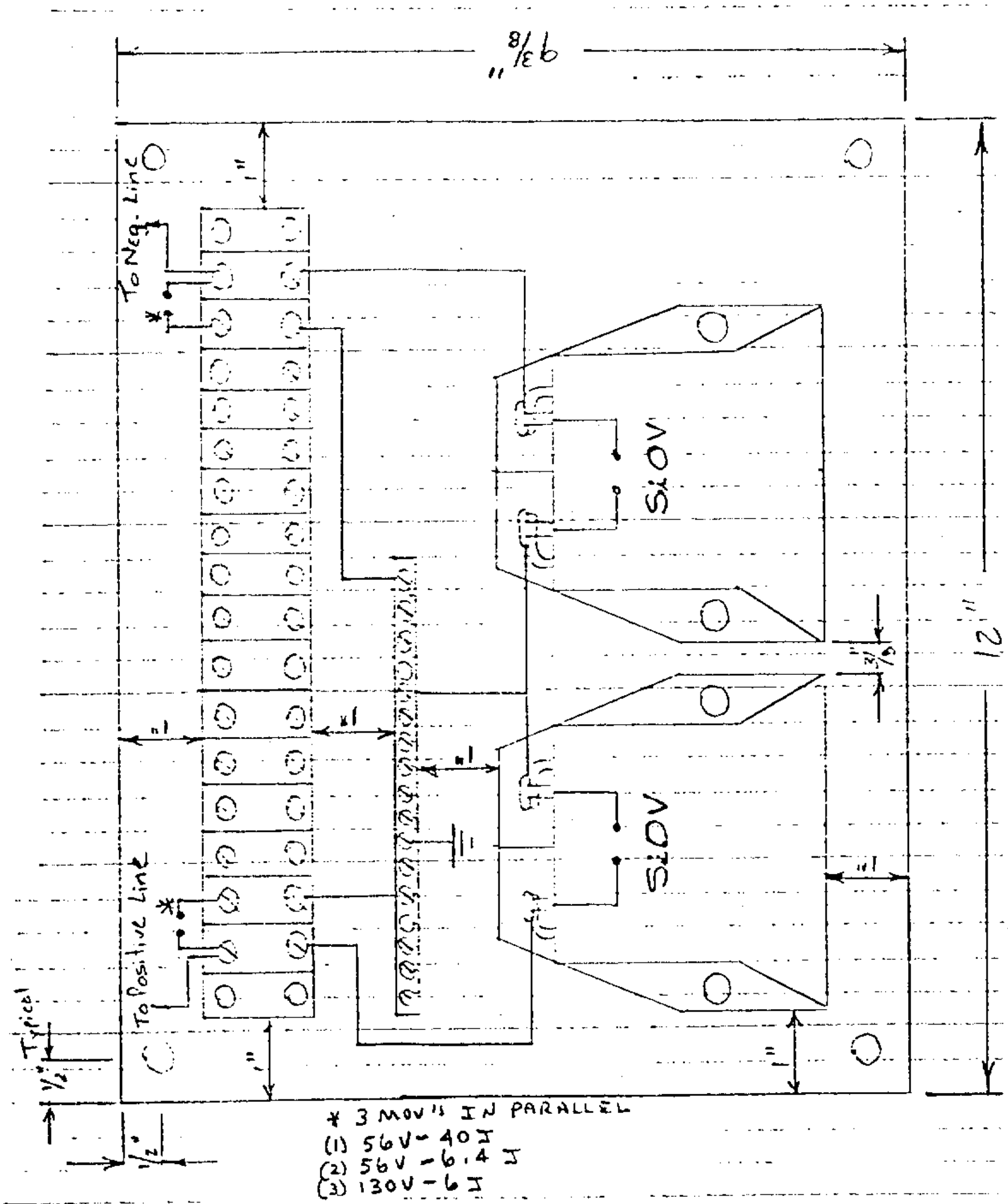

Figure 28. Schematic diagram of metal oxide varistor (MOV) board used for lightening protection of the power supply leads to Bent 4R (Metallized Zinc CP system). The MOV's provide a shunt to ground if large spikes or surges occur in the wiring due to electrical storms. Three MOV's with different energy level ratings were used in parallel to protect against a wide range of electrical spiking and/or surges. The board was mounted in a pull box at Abutment 5R. This location provided the shortest path to ground if electric charge is collected on the metallized zinc surface during an electrical storm event.

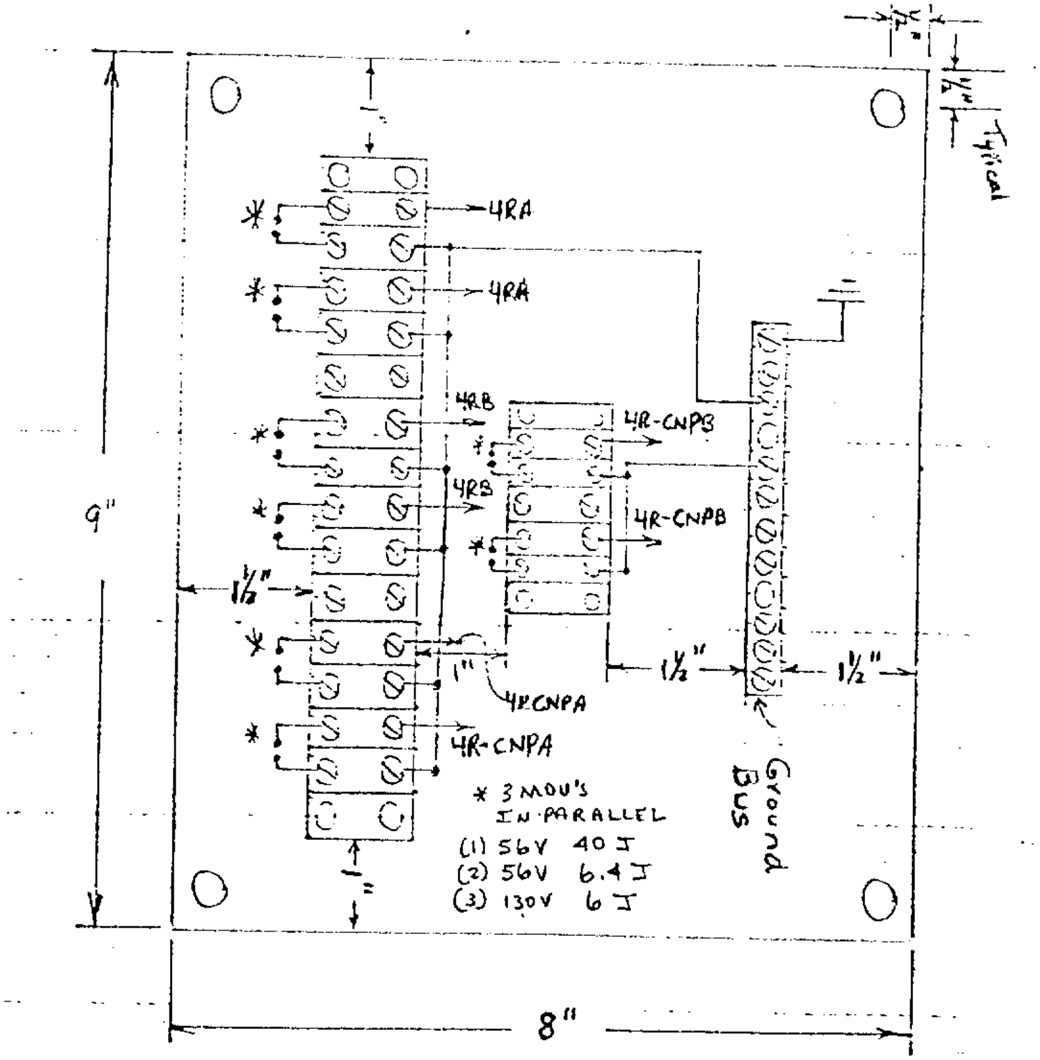

Figure 29. Schematic diagram of metal oxide varistor (MOV) board used for lightening protection of the reference cell leads and corrosion null probe leads to Bent 4R (Metallized Zinc CP system). The MOV's provide a shunt to ground if large spikes or surges occur due to electrical storms. Three MOV's with different energy level ratings were used in parallel to protect against a wide range of electrical spiking and/or surges. The board was mounted in a pull box at Abutment 5R. This location provided the shortest path to ground if electric charge collected on the metallized zinc surface during an electrical storm event.

7.0 REFERENCES

(1) J.E., James B. Bushman, Kenneth C. Clear, Robert N. Kamp, and Wayne J. Swiat, "Cathodic Protection of Concrete Bridges: A Manual of Practice - SHRP-S-372", Strategic Highway Research Program (SHRP), National Academy of Sciences, 1993.

(2) R.A. Carello, D.M. Parks, and J.A. Apostolos, "Development, Testing & Field Application of Metallized Cathodic Protection Coatings On Reinforced Concrete Substructures, California Department of Transportation (Caltrans), 1989.